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Kavaldjiev et al.

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(54) **SAMPLE INSPECTION SYSTEM DETECTOR**

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(22) Filed: **Oct. 24, 2013**

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G01N 21/95	(2006.01)
H01L 27/144	(2006.01)

(52) **U.S. Cl.**

CPC ***G01N 21/9501*** (2013.01); ***H01L 27/1446*** (2013.01)

(58) **Field of Classification Search**

CPC G01N 21/9501; H01L 27/1446

USPC 356/237.5

See application file for complete search history.

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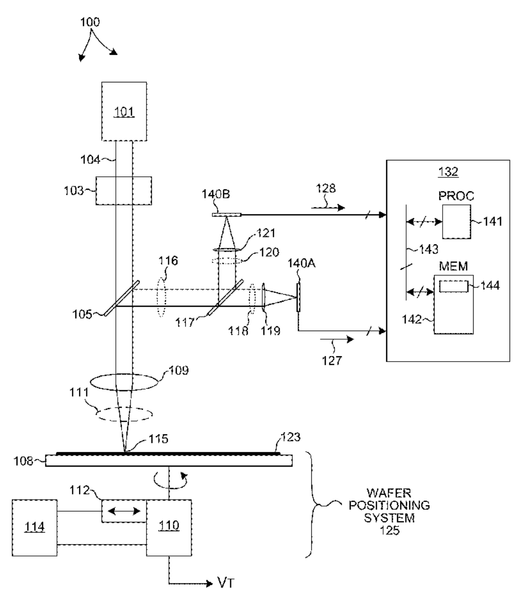
(57) **ABSTRACT**

Methods and systems for enhancing the dynamic range of a high sensitivity inspection system are presented. The dynamic range of a high sensitivity inspection system is increased by directing a portion of the light collected from each pixel of the wafer inspection area toward an array of avalanche photodiodes (APDs) operating in Geiger mode and directing another portion of the light collected from each pixel of the wafer inspection area toward another array of photodetectors having a larger range. The array of APDs operating in Geiger mode is useful for inspection of surfaces that generate extremely low photon counts, while other photodetectors are useful for inspection of larger defects that generate larger numbers of scattered photons. In some embodiments, the detected optical field is split between two different detectors. In some other embodiments, a single detector includes both APDs operating in Geiger mode and other photodetectors having a larger range.

20 Claims, 7 Drawing Sheets



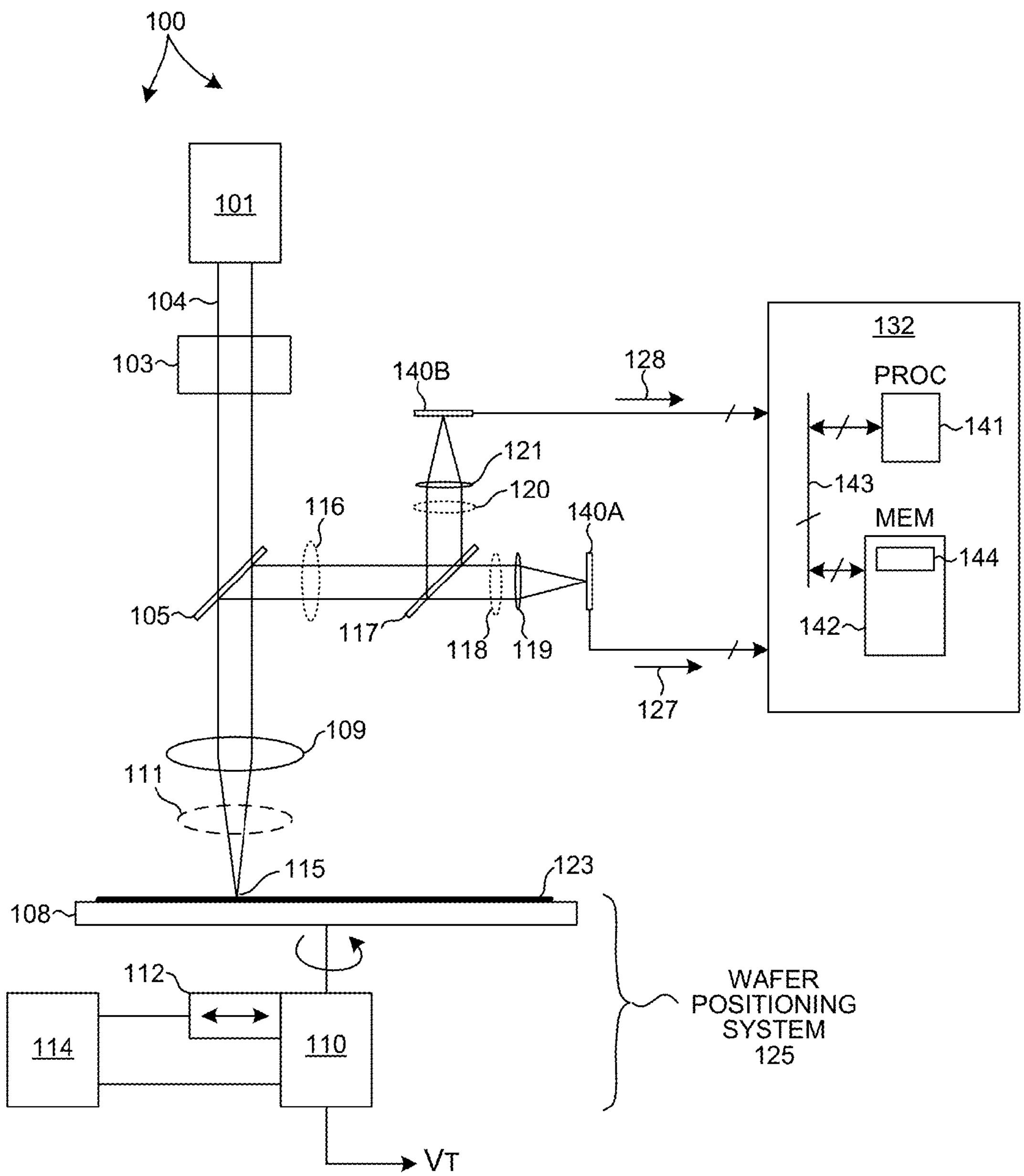

100
101
104
103
140B
128
132
PROC
141
121
143
120
116
140A
MEM
144
105
117
118
119
142
127
109
111
115
123
108
112
114
110
WAFER
POSITIONING
SYSTEM
125
VT

FIG. 1

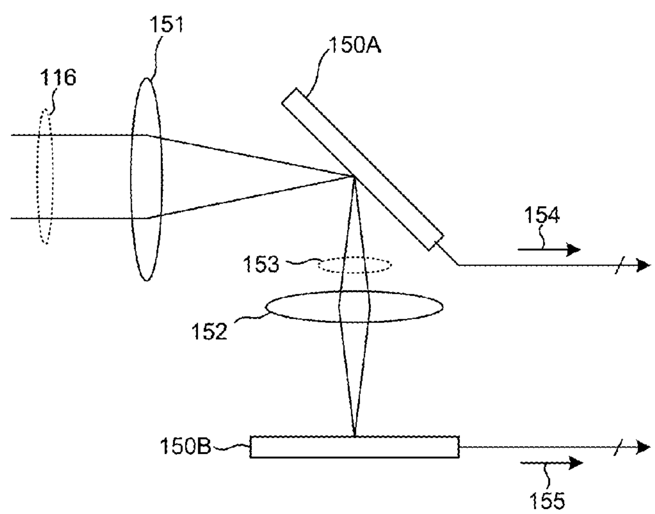

151
150A
116
154
153
152
150B
155

FIG. 2

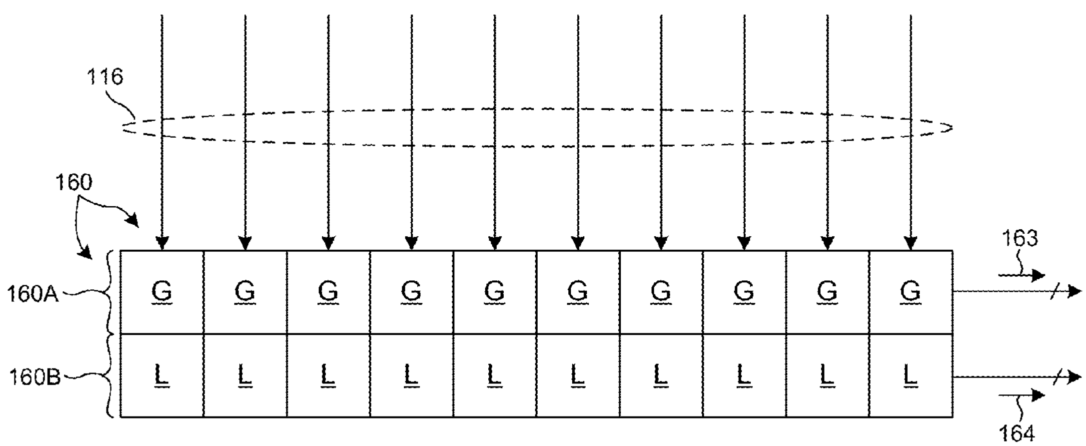

116
160
163
160A
G G G G G G G G G G
160B
L L L L L L L L L L
164

FIG. 3

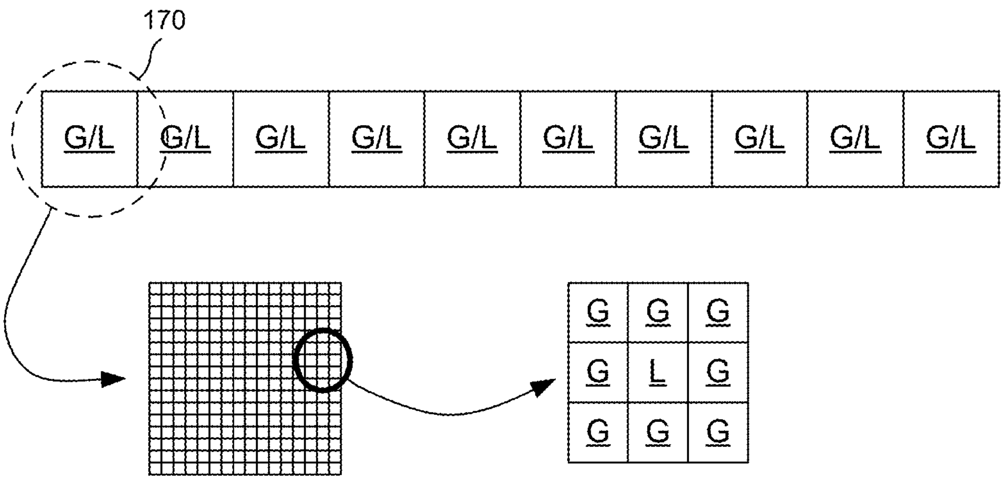


FIG. 4

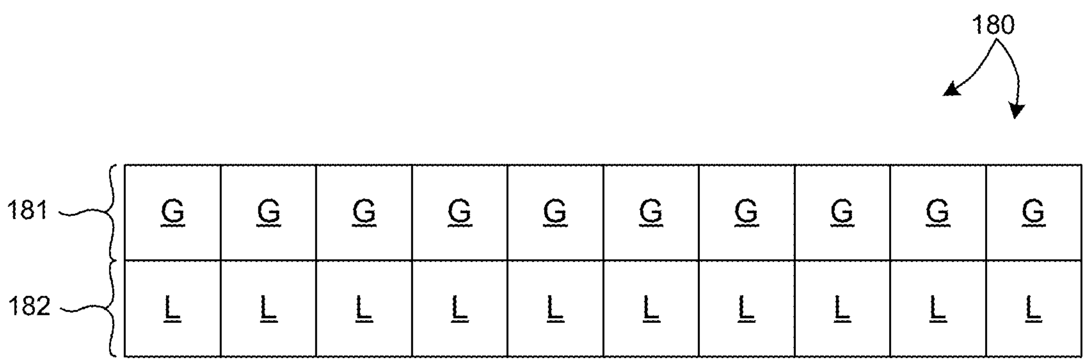


FIG. 5

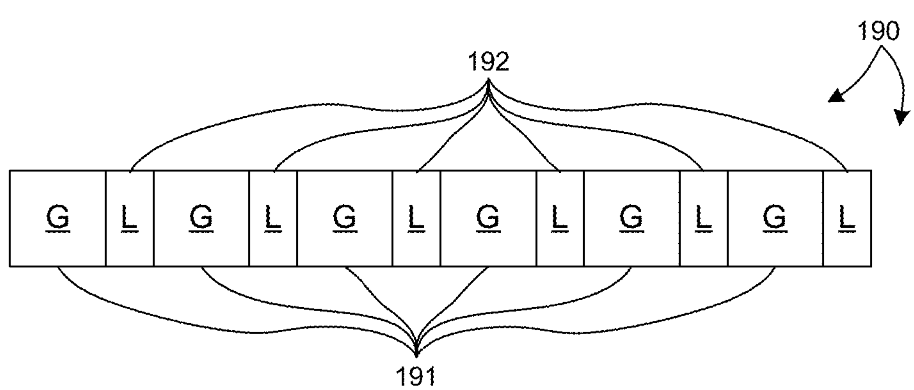


FIG. 6

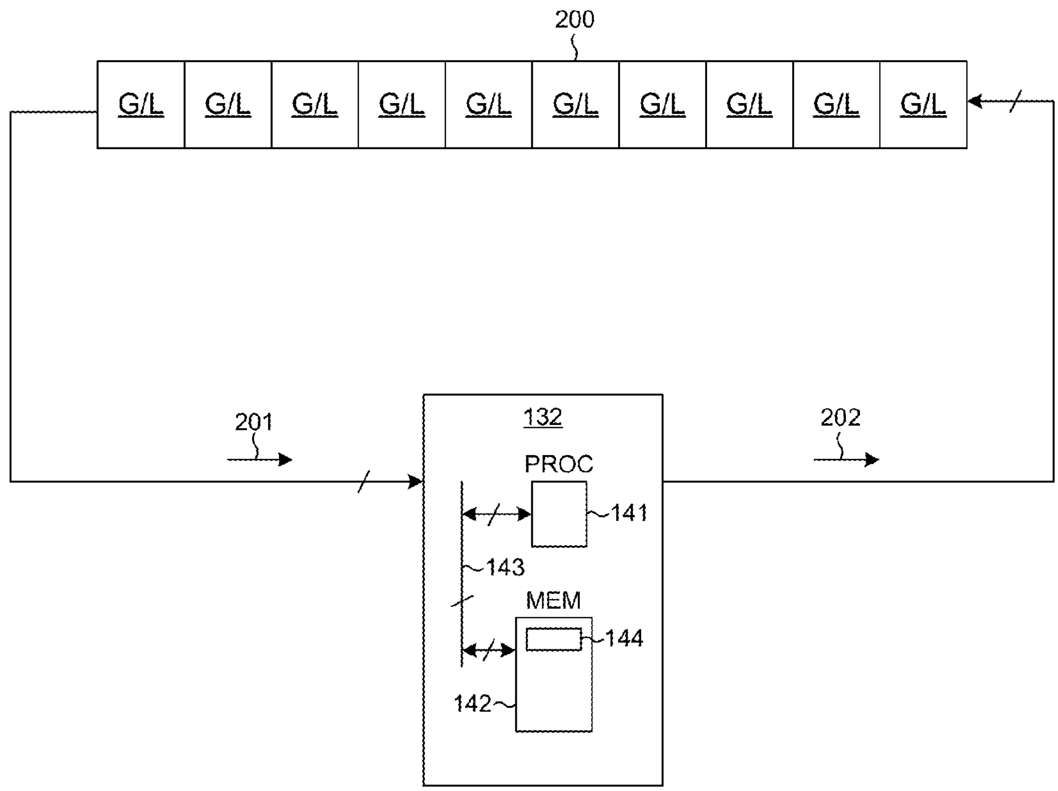

200
G/L
G/L
G/L
G/L
G/L
G/L
G/L
G/L
G/L
G/L
201
132
PROC
141
143
MEM
144
142
202

FIG. 7

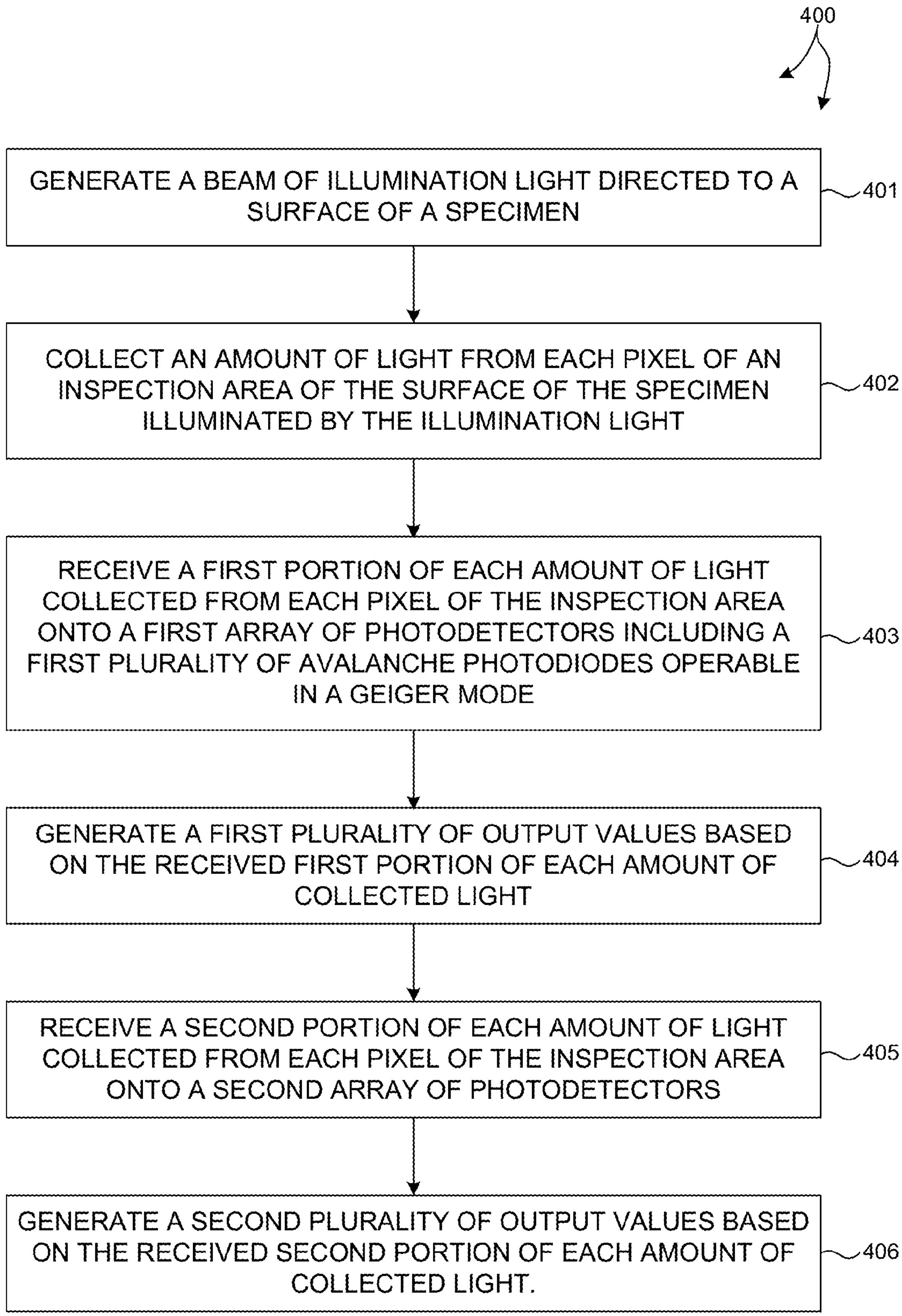

400
GENERATE A BEAM OF ILLUMINATION LIGHT DIRECTED TO A SURFACE OF A SPECIMEN
401
COLLECT AN AMOUNT OF LIGHT FROM EACH PIXEL OF AN INSPECTION AREA OF THE SURFACE OF THE SPECIMEN ILLUMINATED BY THE ILLUMINATION LIGHT
402
RECEIVE A FIRST PORTION OF EACH AMOUNT OF LIGHT COLLECTED FROM EACH PIXEL OF THE INSPECTION AREA ONTO A FIRST ARRAY OF PHOTODETECTORS INCLUDING A FIRST PLURALITY OF AVALANCHE PHOTODIODES OPERABLE IN A GEIGER MODE
403
GENERATE A FIRST PLURALITY OF OUTPUT VALUES BASED ON THE RECEIVED FIRST PORTION OF EACH AMOUNT OF COLLECTED LIGHT
404
RECEIVE A SECOND PORTION OF EACH AMOUNT OF LIGHT COLLECTED FROM EACH PIXEL OF THE INSPECTION AREA ONTO A SECOND ARRAY OF PHOTODETECTORS
405
GENERATE A SECOND PLURALITY OF OUTPUT VALUES BASED ON THE RECEIVED SECOND PORTION OF EACH AMOUNT OF COLLECTED LIGHT.
406

FIG. 8

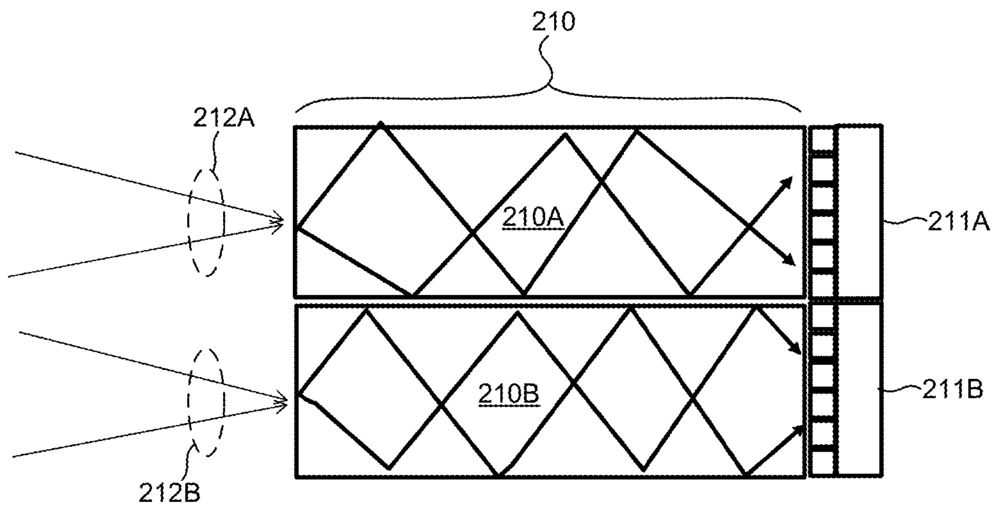


FIG. 9A

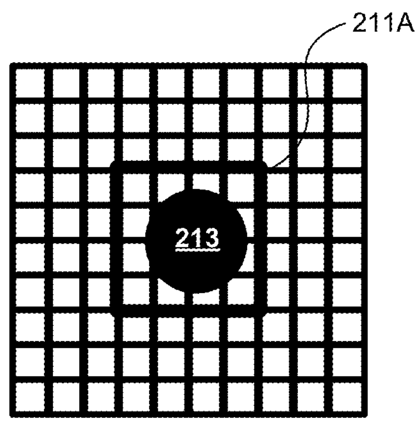


FIG. 9B

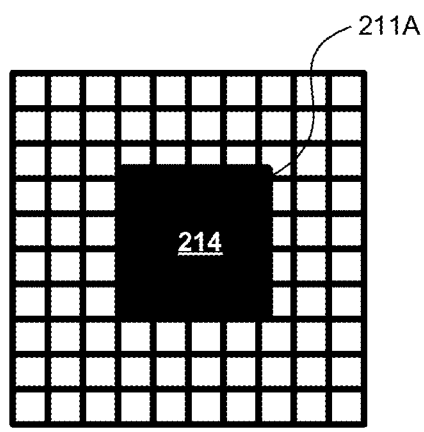


FIG. 9C

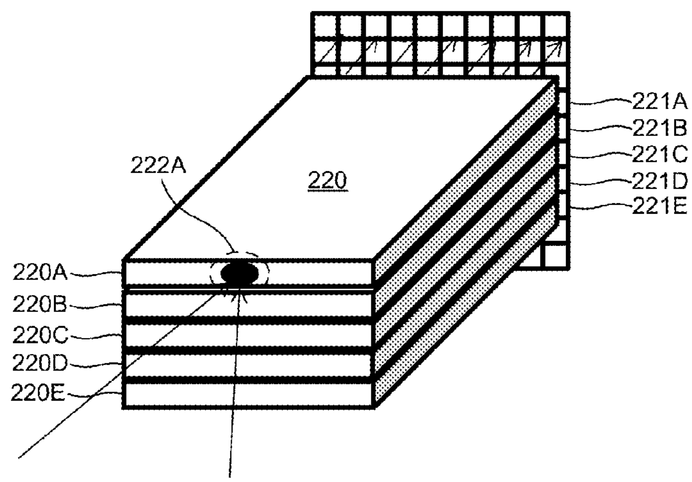

221A
221B
221C
221D
221E
222A
220
220A
220B
220C
220D
220E

FIG. 10

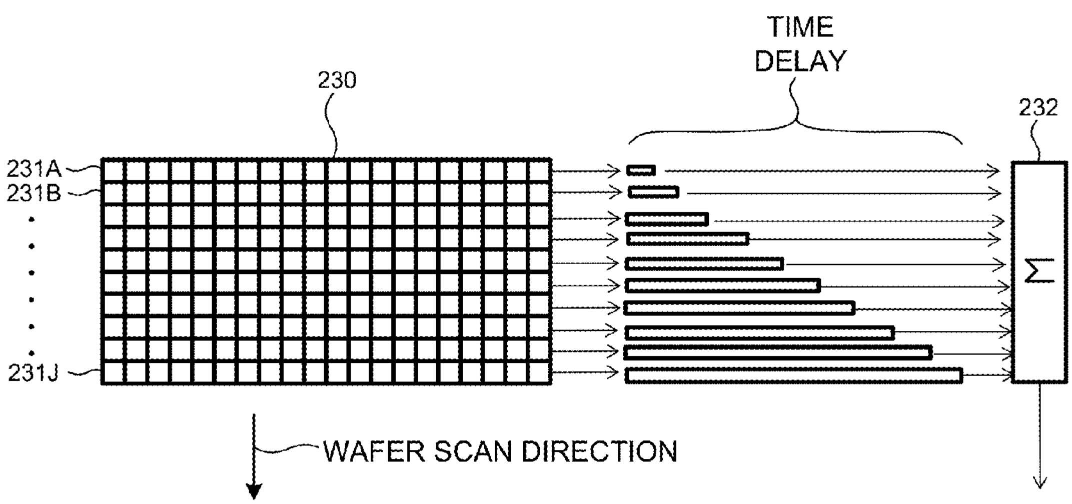

TIME
DELAY
230
232
231A
231B
231J
Σ
WAFER SCAN DIRECTION

FIG. 11

SAMPLE INSPECTION SYSTEM DETECTOR

CROSS REFERENCE TO RELATED APPLICATION

The present application for patent claims priority under 35 U.S.C. §119 from U.S. provisional patent application Ser. No. 61/719,048, entitled "Sample Inspection System," filed Oct. 26, 2012, the subject matter of which is incorporated herein by reference.

TECHNICAL FIELD

The described embodiments relate to systems for surface inspection, and more particularly to semiconductor wafer inspection modalities.

BACKGROUND INFORMATION

Semiconductor devices such as logic and memory devices are typically fabricated by a sequence of processing steps applied to a substrate or wafer. The various features and multiple structural levels of the semiconductor devices are formed by these processing steps. For example, lithography among others is one semiconductor fabrication process that involves generating a pattern on a semiconductor wafer. Additional examples of semiconductor fabrication processes include, but are not limited to, chemical-mechanical polishing, etch, deposition, and ion implantation. Multiple semiconductor devices may be fabricated on a single semiconductor wafer and then separated into individual semiconductor devices.

Inspection processes are used at various steps during a semiconductor manufacturing process to detect defects on wafers to promote higher yield. As design rules and process windows continue to shrink in size, inspection systems are required to capture a wider range of physical defects on wafer surfaces while maintaining high throughput.

One such inspection system is a scanning inspection system that illuminates and inspects a wafer surface. Light collected from the wafer surface is directed to a detector, or an array of detectors, for conversion to electrical signals useful for storage and analysis. Typical detector arrays are limited in their sensitivity due to significant detector noise. Often, this results in inspection systems that operate in a detector noise limited regime, rather than a photon limited, or surface limited regime. In some examples, detector noise is overcome by increasing the amount of illumination power. However, in high-power, laser-based inspection systems, increasing the power density of the incident laser beam may cause damage to the wafer surface. In addition, increasing the illumination power, particularly at short wavelengths, increases cost and may introduce reliability risks.

Previous inspection systems have relied on a variety of detectors, each with different advantages and disadvantages in specific applications. Exemplary detectors include photomultiplier tubes (PMTs), charge-coupled devices (CCDs), PIN diodes, photodiodes, etc. Each of these detectors presents its own challenges and shortcomings. PMTs, for example, are typically bulky, and require high drive voltage. PMTs are also not available in large arrays. CCDs suffer from internal readout noise mechanisms that limit their ultimate sensitivity compared with PMTs.

Avalanche photodiodes (APDs) are small sensors that provide significant gain and require lower drive voltage than PMTs. APDs may be configured in one of two operational modes. In linear mode, the voltage across the APD is set at a value below the break-down voltage. The output of the APD in this mode is a signal that is proportional to the amount of light detected. The gain of the APD may be set at relatively low values (e.g. 100×). In Geiger mode, the voltage across the APD is set at a value above the break-down voltage. In this mode, the gain of the APD becomes very large. Absorption of a single photon may give rise to a large pulse at the output that may be passed through a comparator to generate a clean TTL-like pulse. Thus, very high sensitivity may be achieved by APDs operating in Geiger mode.

However, once a Geiger pulse is trigged the APD is not responsive (i.e., "blind") to the arrival of another photon until a period of time (i.e., the "quench time" associated with the APD) has passed. Once the APD pulse is "quenched", the APD is again able to detect another photon. A typical quench time associated with an APD operating in Geiger mode is a few hundred picoseconds. Unfortunately, this period of blindness limits the dynamic range of APDs operating in Geiger mode, and thus limits their utility in current wafer inspection systems.

Improvements to the sensitivity and dynamic range of array based detectors employed in surface inspection systems are desired to detect defects on a wafer surface with greater sensitivity while avoiding thermal damage to the wafer surface.

SUMMARY

Methods and systems for enhancing the dynamic range of a high sensitivity inspection system are presented.

In one aspect, the dynamic range of the inspection system is increased by directing a portion of the light collected from each pixel of the wafer inspection area toward an array of avalanche photodiodes operating in Geiger mode and directing another portion of the light collected from each pixel of the wafer inspection area toward another array of photodetectors (e.g., an array of avalanche photodiodes operating in linear mode, PIN photodiodes, PMTs, CCDs, etc.). The array of avalanche photodiodes operating in Geiger mode is useful for inspection of surfaces that generate extremely low photon counts. The other array of photodetectors is useful for inspection of larger defects that generate larger numbers of scattered photons. The array of avalanche photodiodes operating in Geiger mode has a different resolution than the other array of photodetectors to optimize the dynamic range of the overall detector system.

In one embodiment, light scattered from each pixel of the inspection area of the surface of a wafer is collected and directed to a beam splitter. The beam splitter directs a portion of the collected light to an array detector that includes a number of avalanche photodiodes (APDs) operating in a Geiger mode. Similarly, the beam splitter directs another portion of the collected light to another array of photodetectors. Both detectors generate output signals usable in combination to determine the presence of anomalies and their characteristics with high sensitivity and large dynamic range.

In another embodiment, light scattered from each pixel of the inspection area of the surface of a wafer is collected and directed to an array detector that includes a number of avalanche photodiodes (APDs) operating in a Geiger mode. A portion of collected light is absorbed by the array detector. Another portion of the collected light is reflected from the surface of the array detector and is directed toward another array of photodetectors. Both detectors generate output signals usable in combination to determine the presence of anomalies and their characteristics with high sensitivity and large dynamic range.

In yet another embodiment, light scattered from each pixel of the inspection area of the surface of a wafer is collected and directed to an array detector configured in a stacked layer arrangement. Incoming light passes through a first array of photodetectors disposed in a first layer at the top surface of detector and a second array of photodetectors are disposed in a second layer of detector **160**, below the first layer. The first array of photodetectors includes a number of avalanche photodiodes (APDs) operating in a Geiger mode.

In another aspect, an array detector may include other photodetectors in addition to APDs operating in a Geiger mode.

In one embodiment a detector includes a linear array of macro-pixels. Each macro-pixel includes a number of APDs operating in Geiger mode and connected in parallel such that multiple photons arriving simultaneously are properly counted. In addition each macro-pixel includes a number of APDs operating in a linear mode. Moreover, each macro pixel may be configured to generate separate output signals; one indicative of the number of photons counted by the APDs operating in Geiger mode, and another indicative of the radiation flux detected by the APDs operating in a linear mode. In some embodiments, light collected from each pixel of an inspection area on the wafer surface is imaged onto a macro-pixel. Hence, a portion of light collected from each pixel of an inspection area of the wafer surface is detected by one or more APDs operating in a Geiger mode and another portion of light collected from the same pixel is detected by another photodetector within the same integrated detector.

In another embodiment a detector includes a linear array of APDs operating in Geiger mode disposed adjacent to another linear array of photodetectors (e.g., APDs operating in linear mode). In some embodiments, light collected from each pixel of an inspection area on the wafer surface is imaged onto adjacent pixels of both linear arrays. Hence, a portion of light collected from each pixel of an inspection area of the wafer surface is detected by one or more APDs operating in a Geiger mode and another portion of light collected from the same pixel is detected by another photodetector within the same integrated detector.

In yet another embodiment a detector includes a linear array of APDs operating in Geiger mode interleaved with another linear array of photodetectors (e.g., APDs operating in linear mode). In some embodiments, light collected from each pixel of an inspection area on the wafer surface is imaged onto adjacent pixels of both linear arrays. Hence, a portion of light collected from each pixel of an inspection area of the wafer surface is detected by one or more APDs operating in a Geiger mode and another portion of light collected from the same pixel is detected by another photodetector within the same integrated detector.

In another aspect, the APDs of a detector array are configured to be switchable between a Geiger mode and a linear mode of operation. In one embodiment, a linear array detector includes drive electronics configured to switch APD elements between a Geiger mode of operation and a linear mode of operation in response to a control signal.

In some embodiments, a number of APDs are switched between a Geiger mode of operation and a linear mode of operation at a particular switching frequency and duration (e.g., pulse width modulated signal). Based on output signals received from the detector array, either or both of the switching frequency and duration values may be adjusted to emphasize or deemphasize output data generated by APDs operating in a Geiger mode.

In some other embodiments, a number of APDs are switched between a Geiger mode of operation and a linear mode of operation based on the saturation level of APDs operating in Geiger mode.

The foregoing is a summary and thus contains, by necessity, simplifications, generalizations and omissions of detail; consequently, those skilled in the art will appreciate that the summary is illustrative only and is not limiting in any way. Other aspects, inventive features, and advantages of the devices and/or processes described herein will become apparent in the non-limiting detailed description set forth herein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified diagram illustrative of one embodiment of an inspection system **100** including a first array of photodetectors including a number of avalanche photodiodes (APDs) operable in a Geiger mode and a second array of photodetectors.

FIG. **2** is a simplified diagram illustrative of a first array of photodetectors including a number of avalanche photodiodes (APDs) operable in a Geiger mode and a second array of photodetectors in another embodiment.

FIG. **3** is a simplified diagram illustrative of a first array of photodetectors including a number of avalanche photodiodes (APDs) operable in a Geiger mode and a second array of photodetectors in yet another embodiment.

FIG. **4** is a simplified diagram illustrative of a detector employing both APDs operable in a Geiger mode and other photodetectors in one embodiment.

FIG. **5** is a simplified diagram illustrative of a detector employing both APDs operable in a Geiger mode and other photodetectors in another embodiment.

FIG. **6** is a simplified diagram illustrative of a detector employing both APDs operable in a Geiger mode and other photodetectors in yet another embodiment.

FIG. **7** is a simplified diagram illustrative of a detector including APDs that are switchable between a Geiger mode and a linear mode of operation.

FIG. **8** is a flowchart illustrative of a method **400** of enhancing the dynamic range of a high sensitivity inspection system.

FIG. **9**A is a diagram illustrative of a light pipe array **210** having light pipe elements **210**A and **210**B disposed in front of macro-pixels **211**A and **211**B, respectively.

FIG. **9**B is a diagram illustrative of a distribution **213** of incoming light **212**A projected onto macro-pixel **211**A depicted in FIG. **9**A without mixing.

FIG. **9**C is a diagram illustrative of a distribution **214** of incoming light **212**A projected onto macro-pixel **211**A with mixing by light pipe **210**A depicted in FIG. **9**A.

FIG. **10** is a diagram illustrative of a light pipe array **220** in another embodiment.

FIG. **11** is a diagram illustrative of a two dimensional array of photodetectors employed to perform one-dimensional measurements with increased dynamic range.

DETAILED DESCRIPTION

Reference will now be made in detail to background examples and some embodiments of the invention, examples of which are illustrated in the accompanying drawings.

FIG. **1** is a simplified schematic view of one embodiment of a surface scanning inspection system **100** that may be used to perform the inspection methods described herein. For simplification, some optical components of the system have been omitted. By way of example, folding mirrors, polarizers, beam forming optics, additional light sources, additional collectors, and additional detectors may also be included. All such variations are within the scope of the invention described herein. The inspection system described herein may be used for inspecting patterned, as well as unpatterned wafers.

As illustrated in FIG. **1**, a wafer **123** is illuminated by a normal incidence beam **111** generated by one or more illumination sources **101**. Alternatively, the illumination subsystem may be configured to direct the beam of light to the specimen at an oblique angle of incidence. In some embodiments, system **100** may be configured to direct multiple beams of light to the specimen such as an oblique incidence beam of light and a normal incidence beam of light. The multiple beams of light may be directed to the specimen substantially simultaneously or sequentially.

Illumination source **101** may include, by way of example, a laser, a diode laser, a helium neon laser, an argon laser, a solid state laser, a diode pumped solid state (DPSS) laser, a xenon arc lamp, a gas discharging lamp, and LED array, or an incandescent lamp. The light source may be configured to emit near monochromatic light or broadband light. In general, the illumination subsystem is configured to direct light having a relatively narrow wavelength band to the specimen (e.g., nearly monochromatic light or light having a wavelength range of less than about 20 nm, less than about 10 nm, less than about 5 nm, or even less than about 2 nm). Therefore, if the light source is a broadband light source, the illumination subsystem may also include one or more spectral filters that may limit the wavelength of the light directed to the specimen. The one or more spectral filters may be bandpass filters and/or edge filters and/or notch filters.

In the embodiment depicted in FIG. **1**, system **100** includes a beam shaping element **103** that reshapes the beam intensity distribution of illumination light **104** to generate a reshaped beam of illumination light **111** that is projected on the surface of wafer **123**. Illumination light **111** is directed to the wafer surface and is incident to the surface of wafer **123** over an illumination spot **115**. In one embodiment, beam shaping element **103** includes a diffractive optical element to generate the desired beam shape. In other embodiments, beam shaping element **103** includes an optical beam shaper to generate the desired beam shape. In other embodiments, beam shaping element **103** includes an apodizer to generate the desired intensity profile. However, due to the attenuation of illumination power associated with apodizers, it is preferable to limit the use of apodizers to inspection modes that are not starved for illumination power. In another embodiment, beam shaping element **103** is a cylindrical lens positioned parallel to the wafer surface as described in U.S. Pat. No. 6,608,676, entitled "System for Detecting Anomalies And/Or Features of a Surface," issued on Aug. 19, 2003, and assigned to KLA-Tencor Corporation, the subject matter of which is incorporated herein by reference in its entirety.

In the embodiment depicted in FIG. **1**, a beam splitter **105** directs the reshaped illumination light to an objective lens **109**. Objective lens **109** focuses the reshaped illumination light **111** onto a wafer **123** at illumination spot **115**. In this manner, illumination spot **115** is shaped and sized by the projection of light emitted from beam shaping element **103** onto the surface of wafer **123**.

In some embodiments, reflected/scattered light is collected and detected from all of the area of illumination spot **115** over a particular sample period by inspection system **100**. In this manner, as much light as possible is collected by inspection system **100**. However, in some other embodiments, reflected/scattered light is collected and detected from a portion of the area of illumination spot **115** over a particular sample period by inspection system **100**.

Optical elements in a collection path of inspection system **100** collect light scattered and/or reflected from the surface of wafer **123** over each pixel of an inspection area on the wafer surface and focus the collected light onto one or more elements of a detector subsystem.

In one aspect, the dynamic range of the detector subsystem is increased by directing a portion of the light collected from each pixel of the wafer inspection area toward an array of avalanche photodiodes operating in Geiger mode and directing another portion of the light collected from each pixel of the wafer inspection area toward another array of photodetectors (e.g., an array of avalanche photodiodes operating in linear mode, PIN photodiodes, PMTs, CCDs, etc.). The array of avalanche photodiodes operating in Geiger mode is useful for inspection of surfaces that generate extremely low photon counts. The other array of photodetectors is useful for inspection of larger defects that generate plenty of scattered photons.

In the embodiment illustrated in FIG. **1**, light scattered from each pixel of the inspection area of the surface of wafer **123** is collected by objective lens **109**. This light passes back through objective lens **109** and impinges on beam splitter **105**. Beam splitter **105** directs collected light **116** toward beam splitter **117**. Beam splitter **117** directs a portion **118** of collected light **116** to imaging lens **119**, which in turn focuses the portion **118** of collected light **116** onto detector **140**A. Detector **140**A includes a number of APDs operating in a Geiger mode. Similarly, beam splitter **117** directs a portion **120** of collected light **116** to imaging lens **121**, which in turn focuses the portion **120** of collected light **116** onto detector **140**B. Beam splitter **117** is configured to apportion collected light **116** between detector **140**A and **140**B. The portions **118** and **120** of collected light **116** may be equal or unequal. For example, in some embodiments, beam splitter may be configured to direct a larger portion of collected light **116** toward detector **140**A, while in other embodiments; beam splitter **117** may be configured to direct a larger portion of collected light **116** toward detector **140**B. As depicted in FIG. **1**, an output signal **127** generated by detector subsystem **140**A and an output signal **128** generated by detector subsystem **140**B are supplied to a computer **132** for signal processing to determine the presence of anomalies and their characteristics.

In another embodiment, illustrated in FIG. **2**, collected light **116** is imaged onto detector **150**A by imaging lens **151**. A portion of collected light **116** is absorbed by detector **150**A which includes a number of APDs operating in Geiger mode. Another portion **153** of collected light **116** is reflected from the surface of detector **150**A and is imaged onto detector **150**B. As depicted in FIG. **2**, an output signal **154** generated by detector subsystem **150**A and an output signal **155** generated by detector subsystem **150**B are supplied to a computer (e.g. computer **132**) for signal processing to determine the presence of anomalies and their characteristics. As illustrated in FIG. **2**, the portion of collected light reflected from detector **150**A is directed to detector **150**B, and is either absorbed by photodetectors of detector **150**B, or lost. However, in other embodiments, detector **150**B may be configured to reflect a portion of incoming light **153** toward yet another detector, and so on. Thus, in general, the cascading arrangement of detectors illustrated in FIG. **2** may be extended to any number of detectors.

In yet another embodiment, illustrated in FIG. **3**, collected light **116** is imaged onto detector **160**. Detector **160** is configured in a stacked layer arrangement where incoming light passes through a first array of photodetectors **160**A disposed in a first layer at the top surface of detector **160** and a second array of photodetectors **160**B are disposed in a second layer of detector **160**, below the first layer. This detector arrangement is sometimes referred to as a "three dimensional detector" because the active area of the detector not only extends in two dimensions across the surface of the detector, but also extends in a third dimension below the surface of the detector.

As depicted in FIG. **3**, the first array of photodetectors **160**A includes APDs operating in Geiger mode. Output signal **163** is generated by detector **160**A. In addition, the second array of photodetectors **160**B includes additional photodetectors (e.g., APDs operating in a linear mode). Output signal **164** is generated by detector subsystem **160**B. Output signals **163** and **164** are supplied to a computer **132** for signal processing to determine the presence of anomalies and their characteristics.

In the embodiment depicted in FIG. **1**, detector subsystem **140** generates bright field signals. However, in general, inspection system **100** may employ various imaging modes, such as bright field, dark field, and confocal. As depicted in FIG. **1**, imaging lens **119** and imaging lens **120** image light collected by objective lens **109** onto detector arrays **140**B and **140**A, respectively. However, in addition, an aperture or Fourier filter, which can rotate in synchronism with the wafer, may be placed at the back focal plane of objective lens **109**. Various imaging modes such as bright field, dark field, and phase contrast can be implemented by using different apertures or Fourier filters. U.S. Pat. Nos. 7,295,303 and 7,130,039, which are incorporated by reference herein, describe these imaging modes in further detail. In another example (not shown), a detector generates dark field images by imaging scattered light collected at larger field angles. In another example, a pinhole that matches the illumination spot **115** can be placed in front of a detector (e.g., detector **140**) to generate a confocal image. U.S. Pat. No. 6,208,411, which is incorporated by reference herein, describes these imaging modes in further detail. In addition, various aspects of surface inspection system **100** are described in U.S. Pat. Nos. 6,271,916 and 6,201,601, both of which are incorporated herein by reference.

In general, optical elements in the collection path of inspection system **100** may include a lens, a compound lens, or any appropriate lens known in the art. Alternatively, any optical element in the collection path may be reflective or partially reflective, such as a mirror. In addition, although particular collection angles are illustrated in FIG. **1**, it is to be understood that the collection optics may be arranged at any appropriate collection angle. The collection angle may vary depending upon, for example, the angle of incidence and/or topographical characteristics of the specimen.

As described hereinbefore with reference to the embodiments depicted in FIGS. **1-3**, detectors **140**A, **150**A, and **160**A, respectively, include a number of APDs operating in a Geiger mode. In some embodiments, detectors **140**A, **150**A, and **160**A may include only APDs operating in a Geiger mode. However, in some other embodiments, detectors **140**A, **150**A, and **160**A may also include other photodetectors in addition to the APDs operating in a Geiger mode.

In one embodiment depicted in FIG. **4**, detectors **140**A, **150**A, and **160**A include a linear array of macro-pixels (e.g., macro-pixel **170**). Each macro-pixel **170** includes a number of APDs operating in Geiger mode and connected in parallel such that multiple photons arriving simultaneously are properly counted. In addition each macro-pixel includes a number of APDs operating in a linear mode. Moreover, each macro pixel may be configured to generate separate output signals; one indicative of the number of photons counted by the APDs operating in Geiger mode, and another indicative of the radiation flux detected by the APDs operating in a linear mode. In some embodiments, light collected from each pixel of an inspection area on the wafer surface is imaged onto a macro-pixel. Hence, a portion of light collected from each pixel of an inspection area of the wafer surface is detected by one or more APDs operating in a Geiger mode and another portion of light collected from the same pixel is detected by another photodetector within the same integrated detector.

In another embodiment depicted in FIG. **5**, detectors **140**A, **150**A, and **160**A are configured similar to detector **180**. Detector **180** includes a linear array **181** of APDs operating in Geiger mode and another linear array **182** of photodetectors (e.g., APDs operating in linear mode) disposed adjacent to linear array **181**. In some embodiments, light collected from each pixel of an inspection area on the wafer surface is imaged onto adjacent pixels of both linear array **181** and linear array **182**. Hence, a portion of light collected from each pixel of an inspection area of the wafer surface is detected by one or more APDs operating in a Geiger mode and another portion of light collected from the same pixel is detected by another photodetector within the same integrated detector.

In another embodiment depicted in FIG. **6**, detectors **140**A, **150**A, and **160**A are configured similar to detector **190**. Detector **190** includes a linear array **191** of APDs operating in Geiger mode interleaved with another linear array **192** of photodetectors (e.g., APDs operating in linear mode). In some embodiments, light collected from each pixel of an inspection area on the wafer surface is imaged onto adjacent pixels of both linear array **191** and linear array **192**. Hence, a portion of light collected from each pixel of an inspection area of the wafer surface is detected by one or more APDs operating in a Geiger mode and another portion of light collected from the same pixel is detected by another photodetector within the same integrated detector.

As described hereinbefore with reference to the embodiments depicted in FIGS. **1-3**, detectors **140**B, **150**B, and **160**B, respectively, include a number of photodetectors. In some embodiments, detectors **140**B, **150**B, and **160**B do not include APDs operating in a Geiger mode, but may include substantially any other photodetector known in the art. A particular detector may be selected for use within one or more embodiments of the invention based on desired performance characteristics of the detector, the type of specimen to be inspected, and the configuration of the illumination. For example, if the amount of light available for inspection is relatively low, an efficiency enhancing detector such as a time delay integration (TDI) camera may increase the signal-to-noise ratio and throughput of the system. However, other detectors such as charge-coupled device (CCD) cameras, PIN photodiodes, APDs operating in a linear mode, phototubes and photomultiplier tubes (PMTs) may be used, depending on the amount of light available for inspection and the type of inspection being performed.

However, in some other embodiments, detectors **140**B, **150**B, and **160**B include APDs operating in a Geiger mode in addition to another type of photodetector. By way of non-limiting example, detectors **140**B, **150**B, and **160**B are configured to the embodiments described with reference to FIGS. **4-6**.

The proportion of APDs operating in Geiger mode in any of detectors **140**A, **140**B, **150**A, **150**B, **160**A, and **160**B relative to other photodetectors may be determined by expected operating conditions of the inspection system **100**. For example, if the photon count is expected to be relatively small, more APDs operating in Geiger mode may be included relative to other photodetectors. Conversely, if the photon count is expected to be relatively large, fewer APDs operating in Geiger mode may be included relative to other photodetectors. In general, the interplay among photon count, light scattering by small defects, quench time of the detectors, and illumination pulse-length (where a pulsed illumination source is used), determines the design of an APD array in Geiger mode with enhanced dynamic range.

For example, in some embodiments, a Q-switched (pulsed) laser is employed. Q-switched lasers are able to deliver high illumination power to the target, thus increasing defect detection sensitivity. The pulse length in a Q-switched laser is typically of the order of 10's of nanoseconds at a repetition rate between a few hundred and 10,000 Hz. Lasers operating in this range are useful in two dimensional inspection applications.

Each pulse of a Q-switched laser may emit up to 10^14 photons illuminating 10^5-10^6 pixels of the sample surface. The scattering induced by extremely small defects on the surface of smooth unpatterned samples may be on the order of 10^-6. Hence, for a small defect, perhaps, 100-1000 photons may arrive at each "macro-pixel" of the detector array. If the quench time of each APD operating in Geiger mode is 300 picoseconds, at most, one hundred photons could be detected by each APD operating in Geiger mode during the 30 nanosecond pulse of the laser. Hence in this example, a few APDs operating in parallel in a Geiger mode in each macro-pixel may provide sufficient dynamic range. For larger numbers of photons, or longer quench times, more APDs operating in parallel in a Geiger mode are required to maintain peak sensitivity.

In some embodiments, the number of APDs configured to operate in Geiger mode is fixed for a particular detector. However, in some other embodiments, any of detectors **140**A, **140**B, **150**A, **150**B, **160**A, and **160**B may be configured to adjust the number of APDs configured to operate in Geiger mode. FIG. **7** illustrates a linear array detector **200** including drive electronics (not shown) configured to switch APD elements of array **200** between a Geiger mode of operation and a linear mode of operation in response to a control command **202** from computer **132**. Exemplary techniques for switching APDs between Geiger and linear mode are described in U.S. Patent Publication No. 2011/0240865 A1, entitled "High Dynamic Range Light Sensor," by Thomas Frach, et al. and published on Oct. 6, 2011, the subject matter of which is incorporated herein by reference in its entirety. In some embodiments, computer **132** switches a number of APDs between a Geiger mode of operation and a linear mode of operation at a particular switching frequency and duration (e.g., pulse width modulated signal). Based on output signals **201** received from detector **200**, either or both of the switching frequency and duration values may be adjusted to emphasize or deemphasize output data generated by APDs operating in a Geiger mode. This can be achieved, for example, by applying a voltage modulation to the APD array such that the detectors are driven back and forth between the linear and Geiger regimes. In some other embodiments, computer **132** determines the saturation level of APDs operating in Geiger mode based on output signals **201** and determines control command **202** to adjust the number of APDs operating in Geiger mode, accordingly.

As depicted in FIG. **7**, inspection system **100** includes a processor **141** and an amount of computer readable memory **142**. Processor **141** and memory **142** may communicate over bus **143**. Memory **142** includes an amount of memory **144** that stores a program code that, when executed by processor **141**, causes processor **141** to determine the desired operational mode of each detector and generate a control signal that causes the detector to adjust the number of APDs operating in Geiger mode.

In one further aspect, a microlens array is disposed in front of the array of photodetectors to focus incoming light collected from each pixel of the inspection area onto the respective active areas of the array of photodetectors. In this manner, losses associated with incoming light incident on "dead space" between adjacent photodetectors of the array is minimized.

In another further aspect, a light pipe array is disposed in front of the array of photodetectors to evenly distribute light collected from each pixel of the inspection area onto each corresponding photodetector pixel. FIG. **9**A illustrates a light pipe array **210** having light pipe elements **210**A and **210**B disposed in front of macro-pixels **211**A and **211**B, respectively. Macro-pixels **211**A and **211**B include a number of APDs operating in Geiger mode. Each of the APD elements (i.e., sub-pixels) that comprise the macro-pixel are connected in parallel such that multiple photons arriving simultaneously are properly counted. To maximize the dynamic range of each macro-pixel, light pipe array **210** evenly distributes incoming light corresponding to each macro-pixel over the active elements (e.g., APDs operating in Geiger mode) of each macro-pixel. In this manner, the likelihood that certain sub-pixels become saturated and unable to properly count incoming photons is minimized. As depicted in FIG. **9**A, incoming light **212**A corresponds with a particular pixel of the inspection area. Light pipe element **210**A receives and mixes the incoming light **212**A. The mixed light is then presented to macro-pixel **211**A as an even distribution of light over each sub-pixel of macro-pixel **211**A. In this manner, macro-pixel **211**A is able to count the number of photons collected a corresponding pixel of the inspection area with maximum dynamic range. Similarly, incoming light **212**B corresponds with another particular pixel of the inspection area. Light pipe element **210**B receives and mixes the incoming light **212**B. The mixed light is then presented to macro-pixel **211**B as an even distribution of light over each sub-pixel of macro-pixel **211**B. FIG. **9**B illustrates a distribution **213** of incoming light **212**A projected onto macro-pixel **211**A without mixing. As depicted in FIG. **9**B, many of the sub-pixels of macro-pixel **211**A are not utilized because photons associated with incoming light **211**A are concentrated on relatively few sub-pixels. As a result, the sub-pixels subject to the concentrated distribution **213** of incoming light **211**A are more easily saturated. Hence, the dynamic range of macro-pixel **211**A is reduced. FIG. **9**C illustrates a distribution **214** of incoming light **212**A projected onto macro-pixel **211**A with mixing by light pipe **210**A. As depicted in FIG. **9**C, all of the sub-pixels of macro-pixel **211**A are utilized because photons associated with incoming light **211**A are evenly distributed over all of the sub-pixels. As a result, particular sub-pixels subject to the even distribution **214** of incoming light **211**A are less likely to saturate. Hence, the dynamic range of macro-pixel **211**A is improved.

FIG. **10** is a diagram illustrative of a light pipe array **220** in another embodiment. As depicted in FIG. **10**, light pipe array **220** includes light pipe elements **220**A-**220**E disposed in front of macro-pixels **221**A-**221**E, respectively. Each of macro-pixels **221**A-**221**E includes a linear array of APDs operating in Geiger mode (i.e., sub-pixels). Each of the APD elements (i.e., sub-pixels) that comprise each macro-pixel are connected in parallel such that multiple photons arriving simultaneously are properly counted. To maximize the dynamic range of each macro-pixel, light pipe array **220** evenly distributes incoming light corresponding to each macro-pixel over the active elements (e.g., APDs operating in Geiger mode) of each macro-pixel. In this manner, the likelihood that certain sub-pixels become saturated and unable to properly count incoming photons is minimized. As depicted in FIG. **10**, incoming light **222**A corresponds with a particular pixel (e.g., linear stripe) of the inspection area. Light pipe element **220**A receives and mixes the incoming light **222**A. The mixed light is then presented to macro-pixel **221**A as an even distribution of light over each sub-pixel of macro-pixel **221**A. In this manner, macro-pixel **221**A is able to count the number of photons collected a corresponding pixel of the inspection area with maximum dynamic range.

In another further aspect, the imaging resolution of the first array of photodetectors including APDs operating in Geiger mode (e.g., array **140**A, **150**A, or **160**A) is different that the imaging resolution of the second array of photodetectors e.g., array **140**B, **150**B, or **160**B). For example, the number of APDs coupled in parallel and operating in Geiger mode at each macro-pixel of a photodiode array determines the dynamic range of that particular photodiode array. As the number of APDs associated with each macro-pixel increases, so does the dynamic range. However, as the number of APDs increases, so does the size of the corresponding macro-pixel for an APD of fixed size. The increase in size of the macro-pixel results in reduced imaging resolution. Hence, a trade-off between imaging resolution and dynamic range of a particular macro-pixel exists based on the number of practically sized APD elements operating in Geiger mode. In a preferred embodiment, the photodetector array receiving more light is designed with a greater number of sub-pixels to increase dynamic range, while another photodetector array receiving less light includes a smaller number of sub-pixels to increase imaging resolution. In the preferred embodiment, one or more of the photodetector arrays includes APDs operating in Geiger mode.

In yet another aspect, the dynamic range of a two dimensional array of photodetectors including APDs operating in a Geiger mode is increased without losing resolution. In the embodiment depicted in FIG. **11**, a two dimensional array of photodetectors each including a number of APDs operating in Geiger mode is employed to perform one-dimensional measurements with increased dynamic range. As depicted in FIG. **11**, two-dimensional array **230** includes a number of rows **231**A-**231**J of photodetectors. A summation module **232**, e.g., implemented by computer **132**, reads out each row element separately, and sums each column of array **230** with a time delay corresponding to their columnar location. Since, the APDs of each photodetector of the array **230** are operating in a Geiger mode, the read out of each row element is a digital value (i.e., photon count value). Hence, the subsequent summation of the column elements is accurately performed without read-out noise. In this manner, a one-dimensional measurement is performed with the resolution determined by the size of the row elements, while the dynamic range is increased by the number of elements integrated in each column. The time delay associated with each column location is based on the scanning speed of the sample being inspected. For example, as the scanning speed of the sample is increased, the time delay is reduced. In some embodiments, the columnar elements are integrated over a straight line. However, in general, the columnar elements can be integrated over an arbitrary curved trajectory.

In some embodiments, drive and readout electronics are constructed on the same substrate as the APDs to reduce cost and improve data processing speed.

In some embodiments, APDs are front illuminated avalanche photodiodes. However, in some other embodiments, back-thinned avalanche photodiodes are employed. The use of back-thinned APDs may be preferred when sensitivity to short wavelength radiation (e.g., deep ultraviolet radiation) is desired.

In some embodiments, the pixel structure of the array is designed to maximize collection efficiency over a range of radiation wavelengths (e.g., DUV and fluorescence signals). In this manner, the array is sensitive to all radiation wavelengths within a prescribed range.

In some embodiments where excess illumination power is available, the central portion of the scattered illuminated field is imaged into a slit aperture. The light spreads out through the aperture and onto the detector array, thus enhancing sensitivity.

In some embodiments, the size of a relatively large particle is estimated based on the output signals generated by detector elements corresponding to the edges of a group of saturated detector elements. For example, a large particle may cause a saturation of signal in the central parts of the image of the defect (i.e., power spectral function of the collector lens) on the detector array. Output signals generated by detector elements on the fringes of the saturated detectors are used to estimate the size of the defect.

In some embodiments of a scanning surface inspection system, each detector generates a single output signal indicative of the light collected from an inspection area illuminated by illumination spot **115**. A single output signal allows for efficient detection of defects with high throughput. In some other embodiments, imaging detectors (i.e., a detector(s) that generate a number of separate output signals indicative of light collected over each pixel of the inspection area illuminated by illumination spot **115**) are employed.

System **100** also includes various electronic components (not shown) needed for processing the scattered signals detected by each detector. For example, system **100** may include amplifier circuitry to receive output signal **127** from detector **140**A and output signal **128** from detector **140**B and to amplify the output signals by a predetermined amount. In addition, an analog-to-digital converter (ADC) (not shown) is included to convert the amplified signals into a digital format suitable for use within processor **141**. In one embodiment, the processor may be coupled directly to an ADC by a transmission medium. Alternatively, the processor may receive signals from other electronic components coupled to the ADC. In this manner, the processor may be indirectly coupled to the ADC by a transmission medium and any intervening electronic components.

In general, processor **141** is configured to detect features, defects, or light scattering properties of the wafer using electrical signals obtained from each detector. The signals produced by the detector are representative of the light detected by each detector. The processor may include any appropriate processor known in the art. In addition, the processor may be configured to use any appropriate defect detection algorithm or method known in the art. For example, the processor may use a die-to-database comparison or a thresholding algorithm to detect defects on the specimen.

In addition, inspection system **100** may include peripheral devices useful to accept inputs from an operator (e.g., keyboard, mouse, touchscreen, etc.) and display outputs to the operator (e.g., display monitor). Input commands from an operator may be used by processor **141** to adjust threshold values used to control illumination power. The resulting power levels may be graphically presented to an operator on a display monitor.

In the embodiment illustrated in FIG. **1**, wafer positioning system **125** moves wafer **123** under a stationary beam of illumination light **111**. Wafer positioning system **125** includes a wafer chuck **108**, motion controller **114**, a rotation stage **110** and a translation stage **112**. Wafer **123** is supported on wafer chuck **108**. Wafer **123** is located with its geometric center approximately aligned with the axis of rotation of rotation stage **110**. In this manner, rotation stage **110** spins wafer **123** about its geometric center at a specified angular velocity, ω, within an acceptable tolerance. In addition, translation stage **112** translates the wafer **123** in a direction approximately perpendicular to the axis of rotation of rotation stage **110** at a specified velocity, VT. Motion controller **114** coordinates the spinning of wafer **123** by rotation stage **110** and the translation of wafer **123** by translation stage **112** to achieve the desired scanning motion of wafer **123** within scanning surface inspection system **100**.

In some embodiments, system **100** may include a deflector (not shown). In one embodiment, the deflector may be an acousto-optical deflector (AOD). In other embodiments, the deflector may include a mechanical scanning assembly, an electronic scanner, a rotating mirror, a polygon based scanner, a resonant scanner, a piezoelectric scanner, a galvo mirror, or a galvanometer. The deflector scans the light beam over the specimen. In some embodiments, the deflector may scan the light beam over the specimen at an approximately constant scanning speed.

Although, the aforementioned detection schemes have been described with reference to an individual illumination spot (e.g., illumination spot **115**), the methods and systems described herein may also be applied analogously to a multi-spot surface inspection system. In a multi-spot inspection system, a number of illumination spots are employed simultaneously. Illumination light is supplied to these illumination spots from one or more illumination sources. Detectors, such as those described herein, may be selectively placed in the collection path of light reflected/scattered from any of the multiple illumination spots. In this manner, defect sensitivity at any of the illumination spots may be improved. Typically, illumination spots are configured with considerable spacing between spots such that inspection results may be interleaved among successive portions of an inspection track and cross-talk at the detectors is minimized. U.S. Pat. Publication No. 2009/0225399, which is incorporated by reference herein, describes multi-spot scanning techniques in further detail.

FIG. **8** illustrates a flowchart of an exemplary method **400** useful for enhancing the dynamic range of detection systems including APDs operable in a Geiger mode. In one non-limiting example, inspection system **100**, described with reference to FIG. **1** is configured to implement method **400**. However, in general, the implementation of method **400** is not limited by the specific embodiments described herein.

In block **401**, a beam of illumination light is generated by an illumination source and directed to a surface of a specimen.

In block **402**, an amount of light is collected from each pixel of an inspection area of the surface of the specimen illuminated by the illumination light.

In block **403**, a first portion of each amount of light collected from each pixel of the inspection area is received onto a first array of photodetectors including a first plurality of avalanche photodiodes operable in a Geiger mode.

In block **404**, a first plurality of output values are generated based on the received first portion of each amount of collected light.

In block **405**, a second portion of each amount of light collected from each pixel of the inspection area is received onto a second array of photodetectors.

In block **406**, a second plurality of output values is generated based on the received second portion of each amount of collected light.

Various embodiments are described herein for an inspection system or tool that may be used for inspecting a specimen. The term "specimen" is used herein to refer to a wafer, a reticle, or any other sample that may be inspected for defects, features, or other information (e.g., an amount of haze or film properties) known in the art.

As used herein, the term "wafer" generally refers to substrates formed of a semiconductor or non-semiconductor material. Examples include, but are not limited to, monocrystalline silicon, gallium arsenide, and indium phosphide. Such substrates may be commonly found and/or processed in semiconductor fabrication facilities. In some cases, a wafer may include only the substrate (i.e., bare wafer). Alternatively, a wafer may include one or more layers of different materials formed upon a substrate. One or more layers formed on a wafer may be "patterned" or "unpatterned." For example, a wafer may include a plurality of dies having repeatable pattern features.

A "reticle" may be a reticle at any stage of a reticle fabrication process, or a completed reticle that may or may not be released for use in a semiconductor fabrication facility. A reticle, or a "mask," is generally defined as a substantially transparent substrate having substantially opaque regions formed thereon and configured in a pattern. The substrate may include, for example, a glass material such as quartz. A reticle may be disposed above a resist-covered wafer during an exposure step of a lithography process such that the pattern on the reticle may be transferred to the resist.

In one or more exemplary embodiments, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media be any available media that can be accessed a general purpose or special purpose computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code means in the form of instructions or data structures and that can be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

Although certain specific embodiments are described above for instructional purposes, the teachings of this patent document have general applicability and are not limited to the specific embodiments described above. In one example, inspection system **100** may include more than one light source (not shown). The light sources may be configured differently or the same. For example, the light sources may be configured to generate light having different characteristics that can be directed to a wafer at the same or different illumination areas at the same or different angles of incidence at the same or different times. The light sources may be configured according to any of the embodiments described herein. In addition one of the light sources may be configured according to any of the embodiments described herein, and another light source may be any other light source known in the art. In some embodiments, an inspection system may illuminate the wafer over more than one illumination area simultaneously. The multiple illumination areas may spatially overlap. The multiple illumination areas may be spatially distinct. In some embodiments, an inspection system may illuminate the wafer over more than one illumination area at different times. The different illumination areas may temporally overlap (i.e., simultaneously illuminated over some period of time). The different illumination areas may be temporally distinct. In general, the number of illumination areas may be arbitrary, and each illumination area may be of equal or different size, orientation, and angle of incidence. In yet another example, inspection system **100** may be a scanning spot system with one or more illumination areas that scan independently from any motion of wafer **123**. In some embodiments an illumination area is made to scan in a repeated pattern along a scan line. The scan line may or may not align with the scan motion of wafer **123**. Although as presented herein, wafer positioning system **125** generates motion of wafer **123** by coordinated rotational and translational movements, in yet another example, wafer positioning system **100** may generate motion of wafer **123** by coordinating two translational movements. For example motion wafer positioning system **125** may generate motion along two orthogonal, linear axes (e.g., X-Y motion). In such embodiments, scan pitch may be defined as a distance between adjacent translational scans along either motion axis. In such embodiments, an inspection system includes an illumination source and a wafer positioning system. The illumination source supplies an amount of radiation to a surface of a wafer over an illumination area. The wafer positioning system moves the wafer in a scanning motion characterized by a scan pitch (e.g., scanning back and forth in one direction and stepping by an amount equal to the scan pitch in the orthogonal direction).

Accordingly, various modifications, adaptations, and combinations of various features of the described embodiments can be practiced without departing from the scope of the invention as set forth in the claims.

What is claimed is:

1. An inspection system comprising:

an illumination source configured to generate a beam of illumination light directed to a surface of a specimen;

one or more optical elements configured to collect an amount of light from each pixel of an inspection area of the surface of the specimen illuminated by the illumination source;

a first array of photodetectors including a first plurality of avalanche photodiodes operable in a Geiger mode, the first array of photodetectors having a first imaging resolution, wherein the first array of photodetectors is operable to receive a first portion of each amount of light collected from each pixel of the inspection area and generate a first plurality of output values based on the received first portion of each amount of collected light; and

a second array of photodetectors having a second imaging resolution, the second array of photodetectors operable to receive a second portion of each amount of light collected from each pixel of the inspection area and generate a second plurality of output values based on the received second portion of each amount of collected light.

2. The inspection system of claim **1**, further comprising:

a beam splitter operable to receive the amount of light collected from each pixel of the inspection area and direct the first portion of each amount of collected light to the first array of photodetectors and direct the second portion of each amount of collected light to the second array of photodetectors.

3. The inspection system of claim **1**, wherein the second portion of each amount of collected light is reflected from a surface of the first array of photodetectors toward the second array of photodetectors.

4. The inspection system of claim **1**, wherein the first array of photodetectors and the second array of photodetectors are interleaved within an integrated detector.

5. The inspection system of claim **1**, wherein the first array of photodetectors and the second array of photodetectors are arranged in a stacked configuration such that the second portion of each amount of collected light passes through the first array of photodetectors to reach the second array of photodetectors.

6. The inspection system of claim **1**, wherein the second array of photodetectors includes a second plurality of avalanche photodiodes operable in a linear mode.

7. The inspection system of claim **6**, wherein the first array of photodetectors includes a third plurality of avalanche photodiodes operable in a linear mode and the second array of photodetectors includes a fourth plurality of avalanche photodiodes operable in a Geiger mode.

8. The inspection system of claim **1**, further comprising:

drive electronics configured to switch the first plurality of avalanche photodiodes between a Geiger mode of operation and a linear mode of operation.

9. The inspection system of claim **8**, wherein the drive electronics switch the first plurality of avalanche photodiodes between a Geiger mode of operation and a linear mode of operation at a switching frequency.

10. The inspection system of claim **1**, further comprising:

a microlens array disposed in front of the first array of photodetectors to focus the first portion of each amount of light collected from each pixel of the inspection area onto the first array of photodetectors.

11. The inspection system of claim **1**, wherein the first and second plurality of avalanche photodiodes are either front illuminated avalanche photodiodes or back-thinned avalanche photodiodes.

12. A method comprising:

generating a beam of illumination light directed to a surface of a specimen;

collecting an amount of light from each pixel of an inspection area of the surface of the specimen illuminated by the illumination light;

receiving a first portion of each amount of light collected from each pixel of the inspection area onto a first array of photodetectors including a first plurality of avalanche photodiodes operable in a Geiger mode, the first array of photodetectors having a first imaging resolution;

generating a first plurality of output values based on the received first portion of each amount of collected light;

receiving a second portion of each amount of light collected from each pixel of the inspection area onto a second array of photodetectors, the second array of photodetectors having a second imaging resolution; and

generating a second plurality of output values based on the received second portion of each amount of collected light.

13. The method of claim **12**, further comprising:

dividing the amount of light collected from each pixel of the inspection area into the first portion of each amount of collected light directed to the first array of photodetectors and the second portion of each amount of collected light directed to the second array of photodetectors.

14. The method of claim **12**, further comprising:

reflecting the second portion of each amount of collected light from a surface of the first array of photodetectors toward the second array of photodetectors.

15. The method of claim **12**, wherein the first array of photodetectors and the second array of photodetectors are interleaved within an integrated detector.

16. The method of claim **12**, further comprising:

transmitting the second portion of each amount of collected light through the first array of photodetectors to reach the second array of photodetectors, wherein the first array of photodetectors and the second array of photodetectors are arranged in a stacked configuration.

17. The method of claim **12**, wherein the second array of photodetectors includes a second plurality of avalanche photodiodes operable in a linear mode.

18. The method of claim **12**, further comprising:

switching the first plurality of avalanche photodiodes between a Geiger mode of operation and a linear mode of operation.

19. An optical detector comprising:

a first array of photodetectors including a first plurality of avalanche photodiodes operable in a Geiger mode, the first array of photodetectors having a first imaging resolution, wherein the first array of photodetectors is operable to receive a first portion of each amount of light collected from each pixel of an inspection area and generate a first plurality of output values based on the received first portion of each amount of collected light; and

a second array of photodetectors including a second plurality of photodiodes operable in a linear mode, the second array of photodetectors having a second imaging resolution, wherein the second array of photodetectors is operable to receive a second portion of each amount of light collected from each pixel of the inspection area and generate a second plurality of output values based on the received second portion of each amount of collected light.

20. The optical detector of claim **19**, further comprising:

drive electronics configured to switch the first plurality of avalanche photodiodes between a Geiger mode of operation and a linear mode of operation.

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